Cetacean Density Estimation from Novel Acoustic Datasets by Acoustic Propagation Modeling

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LONG-TERM GOALS

This is a new project that started in January 2012 and the long-term goals are the application and refinement of population density estimation methods based on detections of marine mammal vocalizations and propagation modeling. The density estimation method is applied to a novel acoustic data set, collected by a single hydrophone, to estimate the population density of false killer whales (*Pseudorca crassidens*) off of the Kona coast of the Island of Hawai'i.

OBJECTIVES

The objectives of this research are to apply existing methods for cetacean density estimation from passive acoustic recordings to novel data sets and cetacean species, as well as refine the existing techniques in order to develop a more generalized model that can be applied to many species in different environmental scenarios. The chosen study area is well suited to the development of techniques that incorporate accurate modeling of sound propagation due to the complexities of its environment. Moreover, the target species chosen for the proposed work, the false killer whale, suffers from interaction with the fisheries industry and its population has been reported to have declined in the past 20 years. Studies of abundance estimate of false killer whales in Hawai'i through mark recapture methods will provide comparable results to the ones obtained by this project. The ultimate goal is to contribute to the development of population density estimation methodologies that will be readily available to those involved in marine mammal research, monitoring, and mitigation.

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APPROACH

Approach to Estimating Population Density of False Killer Whales off Kona, Hawai'i

The methodology employed in this study to estimate the population density of false killer whales off Kona, Hawai'i, is based on the works of Zimmer et al. (2008), Marques et al. (2009), and Küsel et al. (2011). Figure 1 summarizes the steps necessary to estimate population density from passive acoustic data sets and the use of acoustic propagation modeling.

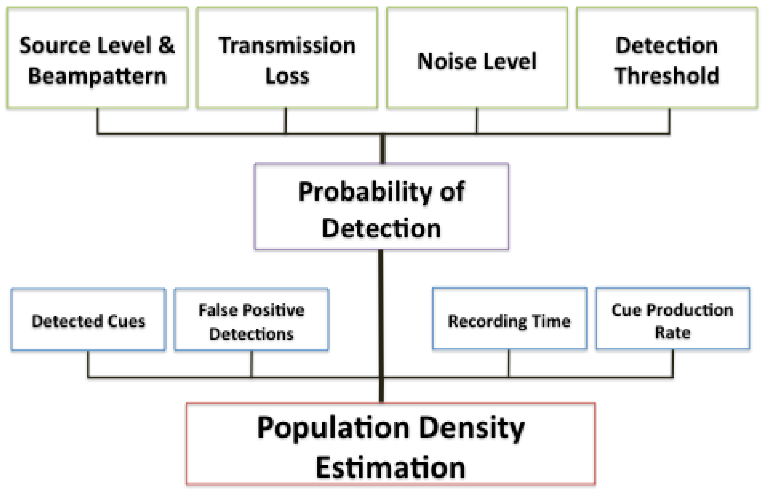

Figure 1. Flow chart with the required steps for estimating the population density of a species.

Following the flow chart with required parameters for density estimation shown in Fig. 1, the acoustic behavior of false killer whales (source level, beampattern, and cue production rate), will come from information available in the literature from previous studies with this species. Acoustic transmission loss of false killer whales' high frequency clicks will be computed using the Bellhop ray tracing propagation model (Porter and Bucker, 1987). From literature information on the target species' diving behavior when emitting sounds, a 3D random distribution of simulated animals will be created taking into account their orientations with respect to the hydrophone. The simulated animals will be placed inside a circle in which the center is the hydrophone location and the radius corresponds to the maximum estimated detection distance for false killer whale clicks in the local environment. Ambient noise levels will be measured from the acoustic data set, and a detector (and classifier) characterization will be made by measuring the signal-to-noise ratio (SNR) of detected clicks as well as the frequency in which clicks in specified SNR bins were detected. The above information is then combined in a Monte Carlo simulation in order to estimate the average probability of detection of false killer whale clicks. Finally, by combining the total number of detected clicks, the number of false positive detections, the total time analyzed, and the click production rate to the average probability of detection we will arrive at an estimate of the population density of false killer whales off the Kona coast for the time period analyzed.

WORK COMPLETED

The work completed in 2012 includes, 1) Literature review of false killer whale acoustic behavior, 2) Obtaining acoustic data and click detections of false killer whales from Dr. Erin Oleson (NOAA Fisheries, Pacific Islands Fisheries Science Center) and Dr. Simone Baumann-Pickering (Scripps Institution of Oceanography), 3) Obtaining environmental parameters from the study area, and 4) Began the investigation into more accurate and efficient propagation modeling practices for complex environments.

1) Literature review of false killer whale acoustic behavior

Madsen et al. (2004) report the acoustic behavior of wild false killer whales in the offshore waters of the Maldives and Sri Lanka. Whistles were not considered in their analysis, despite their presence in the recordings. The authors note to the existence of a fair amount of data on clicks of captive animals. Source parameter estimates were made from data recorded on a vertical array of 3 hydrophones. Au et al. (1995) measured echolocation clicks and vertical and horizontal transmission beam patterns of a false killer whale, in Kaneohe Bay, Oahu, HI, using two 7-hydrophone arrays, while the whale performed target discrimination tasks. One interesting observation from this experiment was that the horizontal transmission beams were narrower than the vertical beams, which is not observed in Atlantic bottlenose dolphins and beluga whales for example. The beams were observed to be directed forward between 0˚ and -5˚ in the vertical and horizontal plane. Finally, they also suggest that the directional character of the false killer whale's beam can be modeled by a planar rectangular aperture transducer having a dimension of 16.1 cm by 10.1 cm. Source levels and center frequencies are also given for 4 types of recorded echolocation clicks.

2) Obtaining acoustic data and click detections of false killer whales

Dr. Erin Oleson, who was responsible for the HARP (High-frequency Acoustic Recording Package, Wiggins and Hildebrand (2007)) deployment and data collection, provided one year worth of acoustic recordings to this project corresponding to the entire year of 2010. The HARP off the Kona Coast of Hawai'i was deployed at a depth of 620 m, being retrieved three times during 2010 for battery and hard drive exchange. Dr. Simone Baumann-Pickering analyzed the data set for false killer whale clicks and provided detection files. Figure 2 shows a spectrogram of a 0.3-second sample of the dataset showing 5 false killer whale clicks.

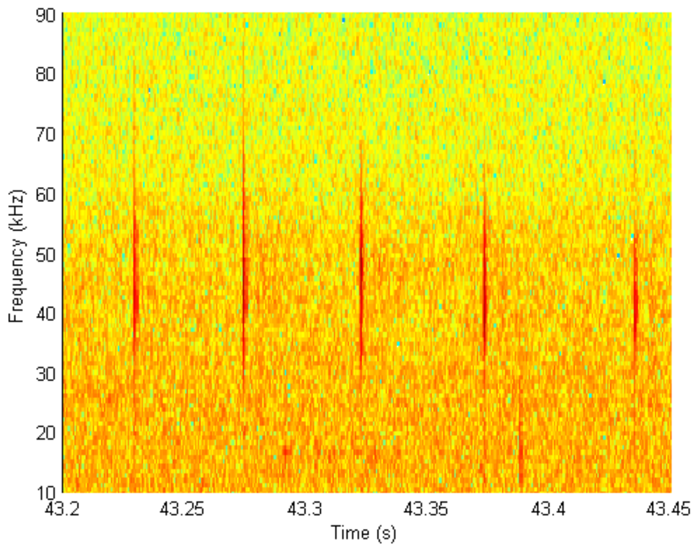

Figure 2. Spectrogram of a subsample of the data set showing recorded clicks of false killer whales. The time axis corresponds to time from the beginning of the file.

3) Obtaining environmental parameters from the study area

The necessary environmental parameters are inputs to the Bellhop propagation model. They consist of bathymetry, sound speed profiles, and bottom composition and properties. The bathymetry of the study area was obtained from NOAA's National Geophysical Data Center (NGDC) Coastal Relief Model with 3-second resolution. Sound speed profiles are derived from 24 oceanographic stations sampled off the Kona Coast between July 3rd and July 12th of 2011, during which temperature and salinity profiles were measured. This information was obtained through Dr. Evan Howell (NOAA Pacific Islands Fisheries Science Center, Ecosystems and Oceanography Division) who was chief scientist of the data collection cruise. Finally, the bottom composition and properties were obtained both from the literature and from NOAA's National Geophysical Data Center (NGDC) Index to Marine & Lacustrine Geological Samples.

4) Efficient propagation modeling for complex environments

Propagation models are usually used in marine bioacoustics to estimate detection distances of marine mammal calls, or to estimate received levels of calls from thousands of simulated animals to a given hydrophone or received levels of man-made noise to the distribution of thousands of simulated animals. A common practice when using 2D propagation models is to calculate the field along equally spaced radial transects around the recording hydrophone or man-made acoustic source and obtain transmission loss at each simulated animal by interpolating the acoustic field between consecutive radials. A separate project being carried out by Drs. Siderius and Küsel, is examining more efficient and accurate ways of performing transmission loss calculations for large distributions of animals and also examines the errors associated with interpolation, especially when the environment is highly range-dependent. Results from this study will be applied to estimate the probability of detecting false killer whales in the density estimator formula.

RESULTS

1) Results on obtaining animal's acoustic behavior and environmental parameters

Important parameters obtained from the literature review on false killer whales (Madsen et al., 2004, Au et al., 1995) are listed below:

Interclick interval (ICI): approx. 25 ms

Click duration: around 30 μs (18 ~ 55 μs)

Estimated source levels: 201 ~ 225 dB re 1 μPa (pp)

190 ~ 215 dB re 1 μPa (rms)

Energy flux density: 145 ~ 168 dB re 1 μPa^2 s

Root-mean-square (RMS) bandwidth: 20 kHz

Peak frequency: around 40 kHz

Centroid frequencies: 33 ~ 68 kHz

Directivity index (DI): 22 ~ 29 dB (depending on the centroid frequencies of the signals)

2) Results on acoustic data analysis

The data set collected off the Kona Coast in 2010 is separated according to each of the 3 deployments of the HARP and named Hawaii # 08-10. The Hawaii 08 deployment was recorded between Dec. 20, 2009 and Mar. 09, 2010 with a duty cycle of 12(interval)/5(on) minutes. The Hawaii 09 deployment was continuously collected between May 01 and Jun. 16, 2010. The Hawaii 10 deployment was recorded between Sep. 30 and Dec. 15, 2010 with a duty cycle of 8(interval)/5(on) minutes. The total number of days the instrument was deployed amounts to 181. Analysis of the detections files revealed that only a few days out of the total 181, had detections of false killer whale clicks. The days during which clicks were detected are listed in Table I and account for only 14 out of the 181 total.

Table I. Days of each month when false killer whale clicks were detected in the 2010 Hawai'i dataset.

Month (2010)	Day of the month
January	-
February	13
March	-
April	-
May	22, 24
June	4, 7
July	-
August	-
September	-
October	3, 8, 10, 17, 18
November	20, 21, 24
December	2

Due to the low sampling periods with existing detections, population density will be estimated for each day independently. Currently, SNR of detected clicks and ambient noise levels are being measured for the above listed days. The false positive detections will also be quantified for the same periods and will be entered in the density estimation formula.

3) Results on obtaining environmental parameters for propagation modeling

Figure 3 shows a map of the study area with the bathymetry data obtained from NOAA's NGDC database. This information will be used to extract bathymetry transects as function of distance from animal to hydrophone to be used as input to Bellhop for calculations of transmission loss. The exact locations of the HARP deployments, depicted as red stars (since the deployments are very close together, only a single star is seen on the map), are also important information that will be used in the transmission loss calculations.

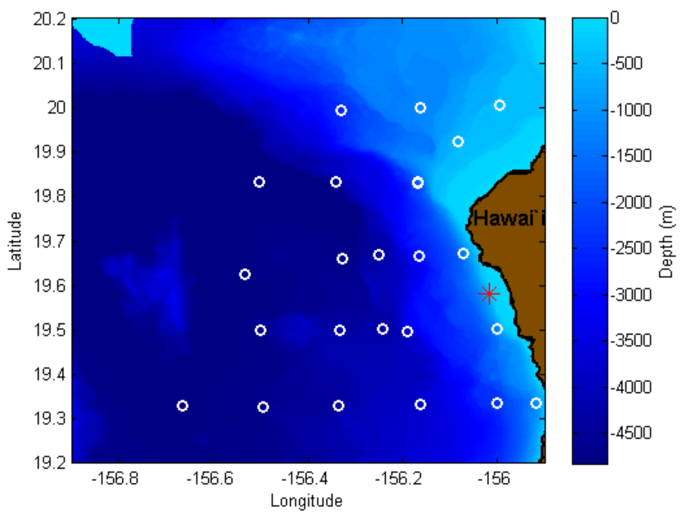

Figure 3. Map of the study area showing the Kona coast, in the Island of Hawai'i, the locations of the HARP deployments (red stars), and the locations of the oceanographic stations (white circles) where CTD profiles were measured giving information on temperature and salinity from which to calculate sound speed profiles.

Sediment cores taken within the study area show that the bottom composition is predominantly mud with organic and volcanic materials. McMurtry et al. (1999) also suggest a sediment cover of approximately 60 cm from cores taken in deeper areas of the study area. Zucca et al. (1982) give a velocity and density models for the crustal structure derived from seismic refraction and gravity data along a transect off the Kona Coast. Compressional wave velocity for the first layer is estimated to be 2.5 km/s and density 2.3 gm/cm^3. Bottom sound speed velocities, densities and attenuations will be assumed (Hamilton, 1980) based on the composition and entered as input to the Bellhop propagation model.

Sound speed profiles were computed from pressure, temperature and salinity profiles by using the Del Grosso equation reformulated by Wong and Zhu for the 1990 International Temperature Scale (Wong and Zhu, 1995). Despite the fact that the environmental data was collected one year after the collection of the data set, we assume they are representative of the study area, at least for the same time period,

and will be used in the calculations of transmission loss. This data set was the only one available for the study area. Another alternative is to use environmental models such as GDEM, from which a comparison of model results and its implications to density estimation can be drawn.

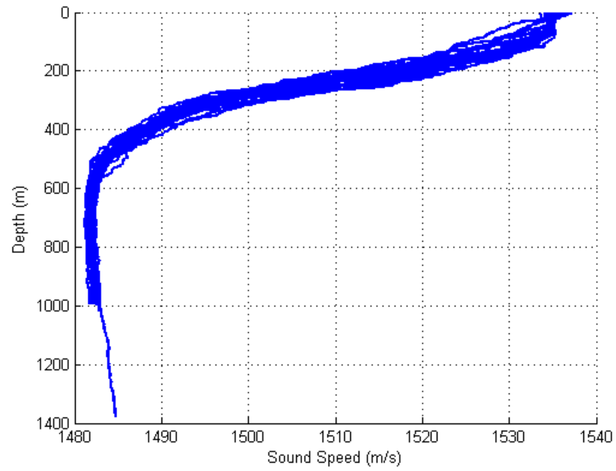

Figure 4. Derived sound speed profiles from 24 oceanographic stations collected within the study area as shown in Fig. 3.

4) Results on efficient propagation modeling

The work on efficient and accurate propagation modeling techniques for marine bioacoustics studies is close to being completed and the results are being written up to be submitted for publication. The important implication to the current one is that the errors associated with interpolation of the acoustic field between radials in range-dependent environments can potentially cause over- or underestimation of the probability of detecting calls. With so many assumptions being made on other parameters such as bottom composition and sound speed profiles for example, it seems more reasonable to propagate the field straight to each animal instead of performing interpolation. Our study suggests that the time of calculations for both techniques are comparable enough so that straight propagation to each animal, however large the distribution, can be a preferable and more accurate modeling practice.

IMPACT/APPLICATIONS

The application of recently developed density estimation methods to different data sets and marine mammal species provides opportunities to test the methodology and make it more general. When studying species that are considered threatened or endangered in any way, as is the case with false killer whales in Hawai'i, it is hoped that density estimation methods from passive acoustics can become a tool to help monitor, study and protect those populations. Development of more efficient and accurate propagation modeling practices, by performing convergence tests and propagating the field straight to each simulated animal instead of performing interpolation for example, to be used in estimating the probability of detection of marine mammal calls is also an interesting component of this project. The ultimate goal is to develop easy-to-use software to make density estimation readily available to the Navy and to those involved in marine mammal research, monitoring, and mitigation. By improving our capabilities for monitoring marine mammals we hope to contribute to minimizing and mitigating the impacts of man-made activities on these marine organisms.

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